Morphodynamics of River, Estuary and Coastal Regions of Southern Karnataka, India: Remote Sensing and GIS Approaches

Final-Synopsis of Ph.D. Work

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Title of the Thesis	**:**	Morphodynamics of River, Estuary and Coastal Regions of Southern Karnataka, India: Remote Sensing and GIS Approaches
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INTRODUCTION

River, estuarine and coastal areas are very important for human and wildlife habitats around the world. It is imperative to understand the processes and morphodynamics of such systems. Numerous interacting processes, such as large- and small- scale hydrodynamics, sediment transport dynamics, growth and decay of bed perturbations, biological processes, and human interferences, make morphodynamics a challenging scientific issue. The present study is focused on evolution and processes of different river basins, estuaries and coastal regions of southern Karnataka, India. This is useful to understand the river basin morphology/tectonic controls, coastal processes, estuarine/spit morphodynamics and shoreline changes.

Fluvial morphology sensitively depends on physical properties of the host rocks, basin topography, climatic effects and neo-tectonic activities over different time periods (Fig. 1). Thus, the drainage system of a region records the tectonic deformation and stages of its evolution (Gloaguen, 2008). River basin or watershed (also referred to as catchments) is the boundary conditions within which rivers operate and show their associated morphological attributes related to the constituent parameters of landforms and drainage (Chorley, 1969). Basin morphometric analysis is an important technique to evaluate the behaviour of hydrological system, which provides quantitative specification of basin geometry to understand initial slope or inconsistencies in rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964; Esper Angillieri, 2008). In order to understand the drainage pattern and the evolution of river drainage basins, geomorphology and morphometric parameters of different river basins have been mapped and interpreted (Fig. 1). Finally, sub-basin-wise prioritisation was executed to determine the deficit and surplus zones of groundwater.

River migration or erosion of the channel boundary has been described as river bank erosion, meander migration and lateral channel changes. Bank erosion is the result of complex natural processes that depend on inchannel hydraulic conditions and physical character of the banks; both are highly variable within a single river, as well as between rivers (Piegay et al., 2005). Lateral channel change can be considered as the net effect of smaller scale processes including direct corrosion (Hooke, 1979), bank failure (Lawler et al., 1997) and large-scale seepage (Davis and Gregory, 1994). Combinations of these

processes can lead to meander migration, channel avulsion or channel expansion. It is important to note that bank erosion occurs mainly on outside bends, but can also occur on straight sections and inside bends (Hooke, 1980). To find out the significant changes due to neotectonic activities, formation of braided islands, variation in flow intensity and anthropogenic interventions in the course of the Netravati and Gurpur rivers have been studied through space and time.

Evolution of coastal systems is the result of morphodynamics that develop in response to change in external conditions (Wright and Thom, 1977) and controlled by various factors viz., morphology and geology of the catchment, size of the catchment area, nature of sedimentation basin, climate leading to rainfall and river discharge at coastal zone, freshwater input, and coastal hydrodynamics - waves, tides and currents (Albert and Jorge, 1998). In addition, these factors have a considerable impact on adjacent shorelines that they interrupt by influencing the sediment budget (Stive and Wang, 2003). Estuarine system is found along several coastlines in the world irrespective of geological setting, energy regime, and depositional environment. Different estuarine systems of southern Karnataka have been studied, to understand the hydrodynamic processes and their role in morphological changes of estuarine mouth, erosion/accretion patterns of estuarine banks and islands. Estuarine eco-system is highly valuable and attracts a variety of human activities, such as navigation, recreation, fishing, aquaculture, economic activity in the border zone, sand mining, land reclamation and in some cases oil or gas mining.

Rate of change in coastal landforms and shoreline position is important in demarcation of setback line, hazard zoning, erosion-accretion aspects, sediment budgeting, and conceptual/predictive modeling of coastal morphodynamics (Sherman and Bauer, 1993; Al Bakri, 1996; Zuzek et al., 2003). Shoreline changes can be estimated employing various conventional techniques like, end point rate (Fenster et al., 1993), average rates, linear regression, and jack-knifing (Dolan et al., 1991). For estimating the rate of change in shoreline position, the linear regression (LR) method has proved to play an important role as it minimizes potential random error and short-term variability (Douglas and Crowell, 2000; Allan et al., 2003; Maiti and Bhattacharya, 2009; Avinash et al., 2010). An attempt has been made to reconstruct the past shoreline and project future shoreline positions between Talapadi (southern most part of Dakshina Kannada coast) and Yermal (middle part of the Udupi coast), using ancillary data,

satellite images and statistical techniques. Also, morphology of seven spits which fall in the study have been studied in detail with respect to their size and areal extent, dynamics and factors responsible for evolution during the last 95-years.

OBJECTIVES OF THE PRESENT STUDY

The objectives of this investigation are:

1. To understand drainage pattern and infer the lithological and structural controls on the evolution of river drainage basins of the southern coastal Karnataka,
2. To reveal the role of various processes on migration of river channels, particularly Netravati and Gurpur,
3. To understand the hydrodynamic processes and their role in evolution of coastal landforms,
4. To estimate rate of shoreline changes, reconstruction of past and predict future shoreline positions,
5. Understanding morphological changes and quantitative estimation of spits in the study area, and
6. To understand the impact of anthropogenic activities on coastal environments.

ORGANISATION OF CHAPTERS

The thesis comprises of seven chapters which highlights an overview of ongoing fluvial, estuarine and coastal morphodynamic processes based on integrated techniques of remote sensing, GIS and statistical computations as well as field investigations. A brief account of the contents dealt with in each chapter is given below.

CHAPTER-I: General Introduction

The first chapter covers general introduction behind the whole study (Fig. 1), which is divided into different subsections, such as: (1) A brief introduction pertaining to river, estuary and coastal morphodynamic processes and their role on fluvial and coastal morphological changes; (2) Objectives of the present study; (3) An overview of the study area – geology, physiography and climate, offshore and nearshore bathymetry, waves, and currents.

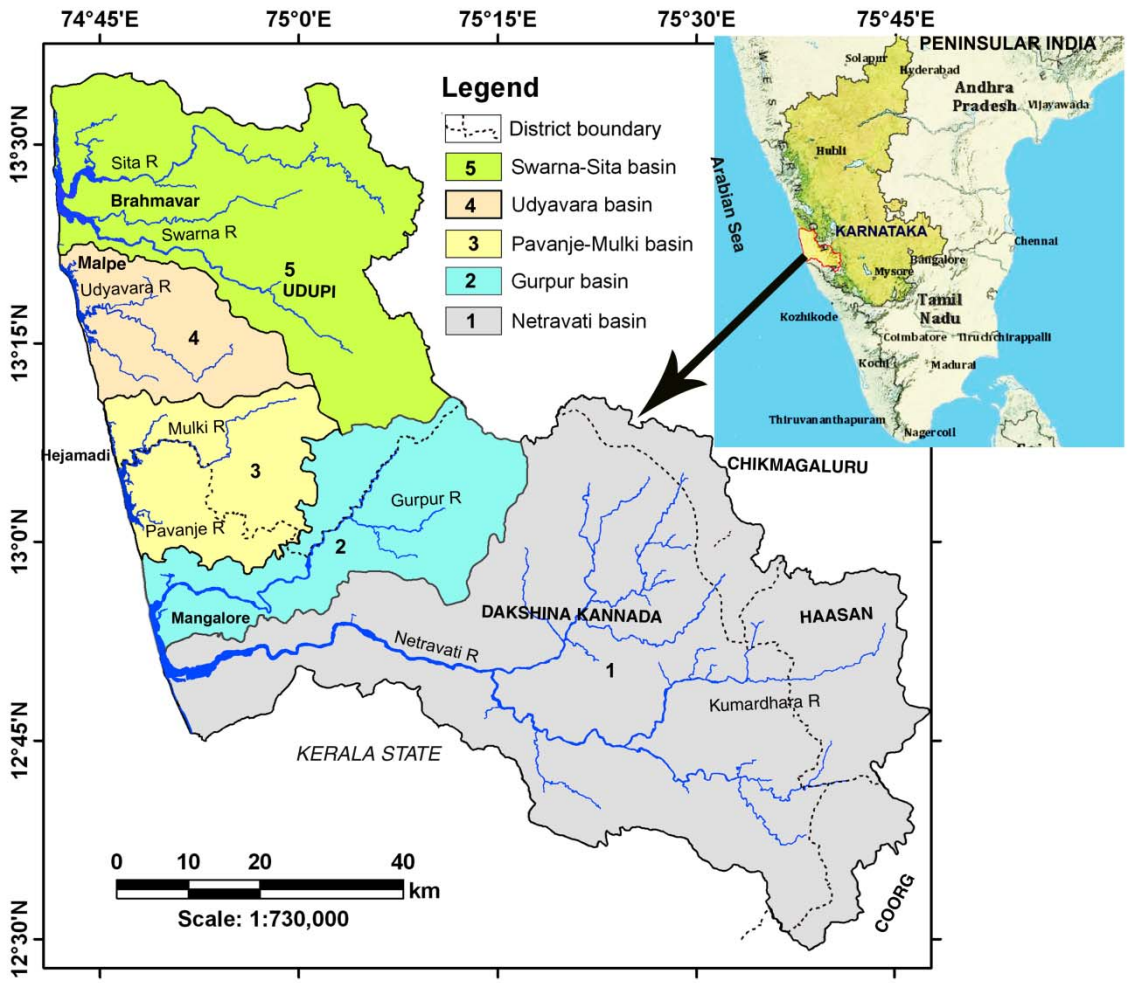

Fig. 1: Location map of the study area showing the extent of different river basins and coastal stretch of southern Karnataka, India.

CHAPTER-II: Geomorphology and Morphometry of River Basins

This chapter deals with the analyses of geomorphic- and drainage-characteristics of five different river basins – (i) Netravati, (ii) Gurpur, (iii) Pavanje-Mulki, (iv) Udyavara, (v) Swarna-Sita – of southern Karnataka, India (Fig. 1). To understand the influence of structural and lithological controls, various drainage patterns were identified in highland, midland and coastal regions. Whereas, stream orientation analysis was computed for 2nd, 3rd and 4th order streams of the basins to evaluate the directions and controlling factors of drainage network. Based on lithological characteristics, sub-basin-wise geomorphological features were interpreted and mapped. Further, areal extent of each geomorphic unit has been quantified to understand the prospect of groundwater. Quantitative analyses of basin characteristics have been computed from linear, areal and relief morphometric parameters, using the established mathematical equations. The study

reveals that the geomorphology and morphometric parameters are the good proxies to evaluate the deficit and surplus zones of groundwater for river basins/watersheds. Finally, geomorphology and morphometric parameters have been used to prioritize the sub-basins and identify the most deficit/surplus zones of groundwater. Basin-wise stream orientation analysis revels that the streams of the studied basins are controlled either by lithology or by structure. Hence, validation by conducting the ground based surveys is necessary.

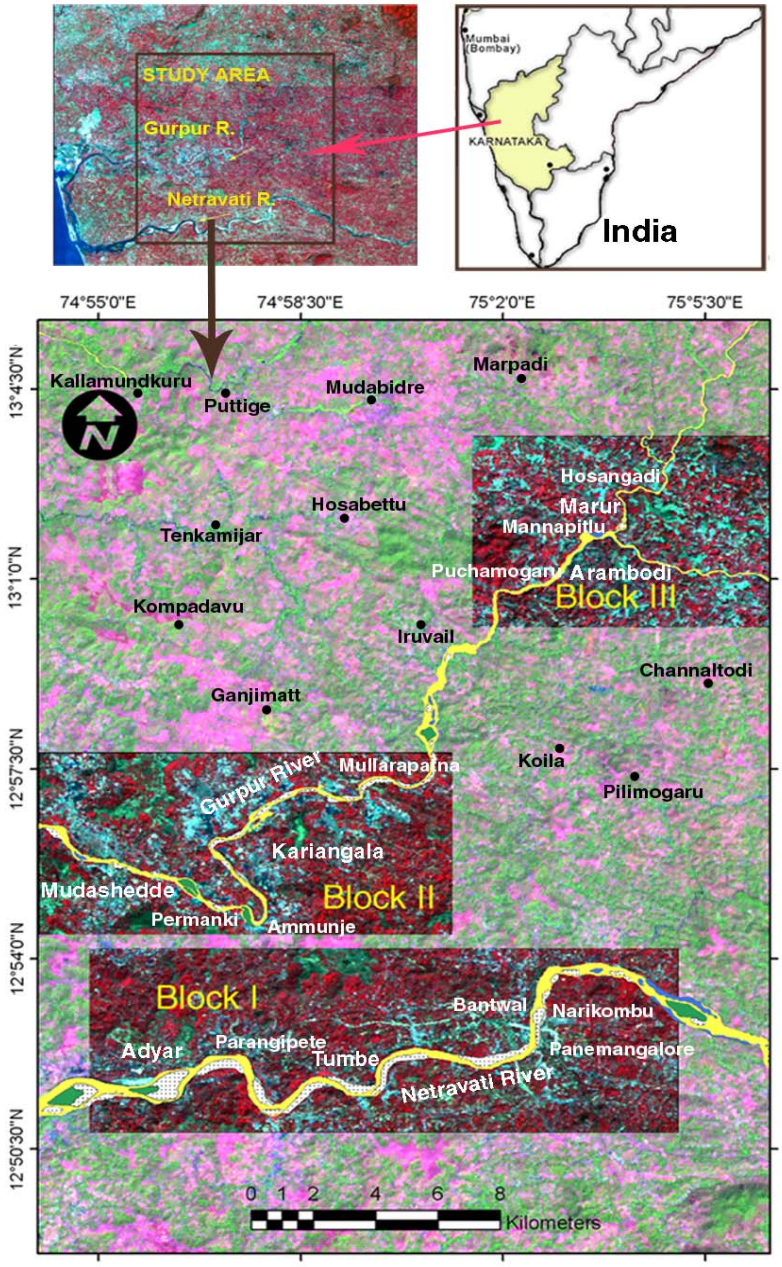

Fig. 2: Part of the Netravati (Block-I) and Gurpur (Block-II & III) river courses investigated in the present study.

CHAPTER-III: River Migration: Examples from the Netravati and Gurpur Rivers

In this chapter, an attempt has been made to quantify the changes in the course of Netravati and Gurpur (N-G) rivers, and investigate the causes of their migration through space and time (Fig. 2). The N-G river basins are tectonically active due to a number of seismically active faults/lineaments and their proximity to Mulki-Pulicat Lake axis. Gradient of the river channels has gradually reduced (after ~10 km from their origin) and has forced the rivers to flow slowly in meandering and zigzag paths. The nature and intensity of meanders are governed by geological and tectonic conditions of the river basins. Significant changes in the course of river channels have been detected in three blocks – Block-I (Netravati) and Blocks-II and III (Gurpur) – and studied in detail by employing multi-dated satellite images; topographic, geological, gravity, and seismotectonic maps. Interpreted results of various thematic maps manifest that migration of the river channels is controlled by active faults, neotectonics, formation of braided islands or holms, variation in rainfall/flow intensity, riparian vegetation and anthropogenic activities like construction of vented dams, sand mining and other interventions.

CHAPTER-IV: Coastal and Estuarine Processes for Evolution of Braided Islands

This chapter is focused on role of coastal and estuarine processes for evolution of braided islands and estuarine banks/mouths of different estuaries - Swarna, Udyavara, Mulki, Pavanje, Gurpur and Netravati - by integrating the results of field surveys, topographic data, satellite images and hydrodynamic modelling in GIS context. Hydrodynamics of the nearshore and estuarine regions are studied through modelling (MIKE–21HD), and probable flow pattern that is responsible for morphological changes. Finally, a conceptual Inverse Distance Weighted (IDW) interpolation model has been generated to evaluate and predict the possibilities of floods on braided islands, during high tides, heavy rainfall and/or sea-level rise.

The study indicates that the modelled versus measured current components (U & V) yield good match between the measured and simulated currents. The current speed during ebb tide is stronger than the flood tide since the wind driven currents are also in

the same direction (Fig. 3). Current speed inside the Swarna and Mulki-Pavanje estuaries remained at an average of about 10-20 cm/s and 7-35 cm/s, respectively; however strong currents of about more than 40 cm/s prevailed at the mouth. Hence, these processes indicate that flooding and drying occurred in semidiurnal period therefore tidal pools were formed in the estuary and estuarine channels disrupting the connectivity of the estuary with the coastal waters.

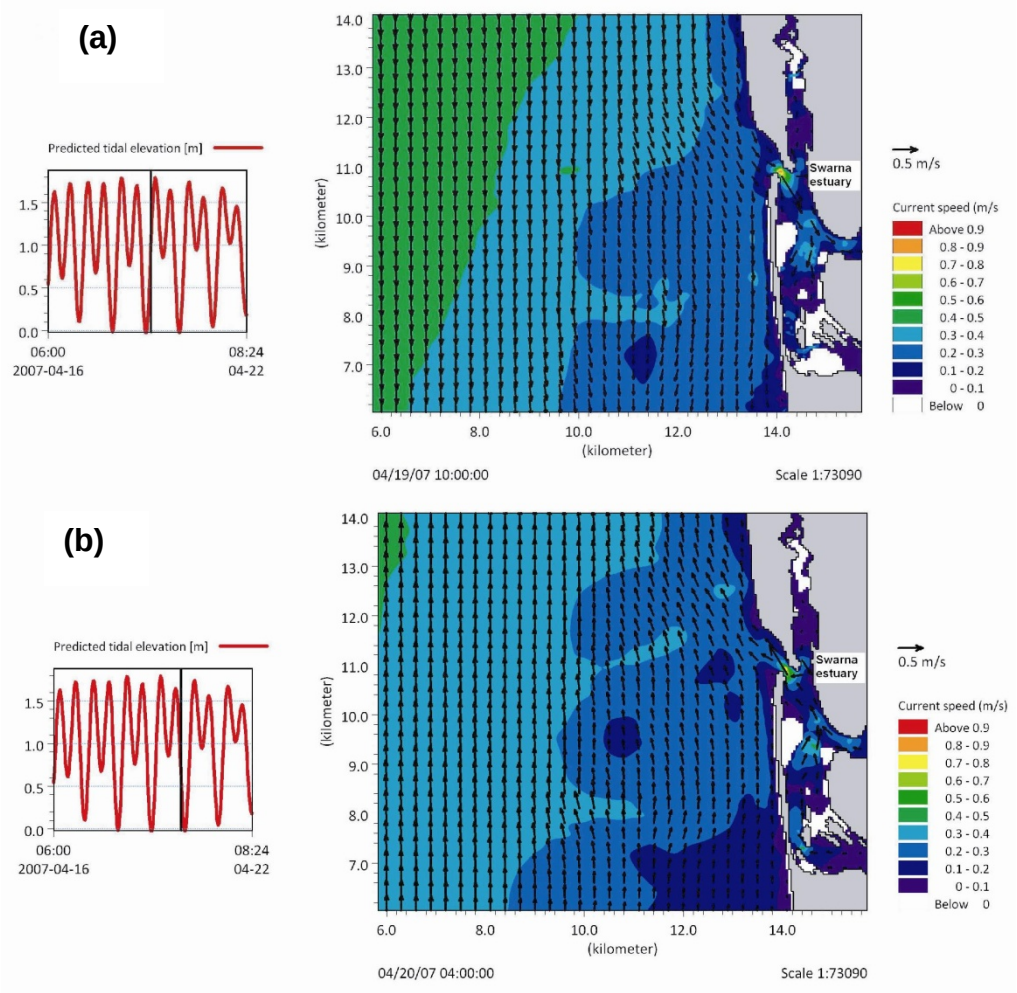

Fig. 3: A typical flow pattern around the Swarna estuary and corresponding tide elevations, flood currents (a), and ebb currents (b).

Coastal and tidal currents off Udupi and Mangalore contribute sediments to the adjacent barrier spits, and make the spits to grow in the direction of longshore sediment transport. This, in turn, must be responsible for erosion of Right banks (Rbs) and accretion of Left banks (Lbs) of the estuaries studied and orientation of islands. From the IDW interpolation model, it is found that the braided islands and shoals of the estuaries are partially or fully flooded during the highest high tide, heavy rains during southwest

monsoon and/or sea-level rise. In this regard, estuary-wise impacts of flooding on braided islands are quantified and discussed in detail in this chapter.

CHAPTER-V: Shoreline Changes and Predictions

In Chapter-V, an attempt has been made to reconstruct the past shoreline positions and project future positions between Talapadi (southern most part of Dakshina Kannada coast) and Yermal (middle part of the Udupi coast), using ancillary data, satellite images and statistical techniques. The study area has been divided into four littoral cells (LC-I to LC-IV), and each cell into a number of transects at uniform intervals. The rate of change in shoreline position has been estimated using the statistical linear regression method and cross-validated with regression coefficient (β) and Root Mean Square Error (RMSE) methods. Past shoreline positions have been demarcated and future positions are estimated for the time periods of 10- and 24-years.

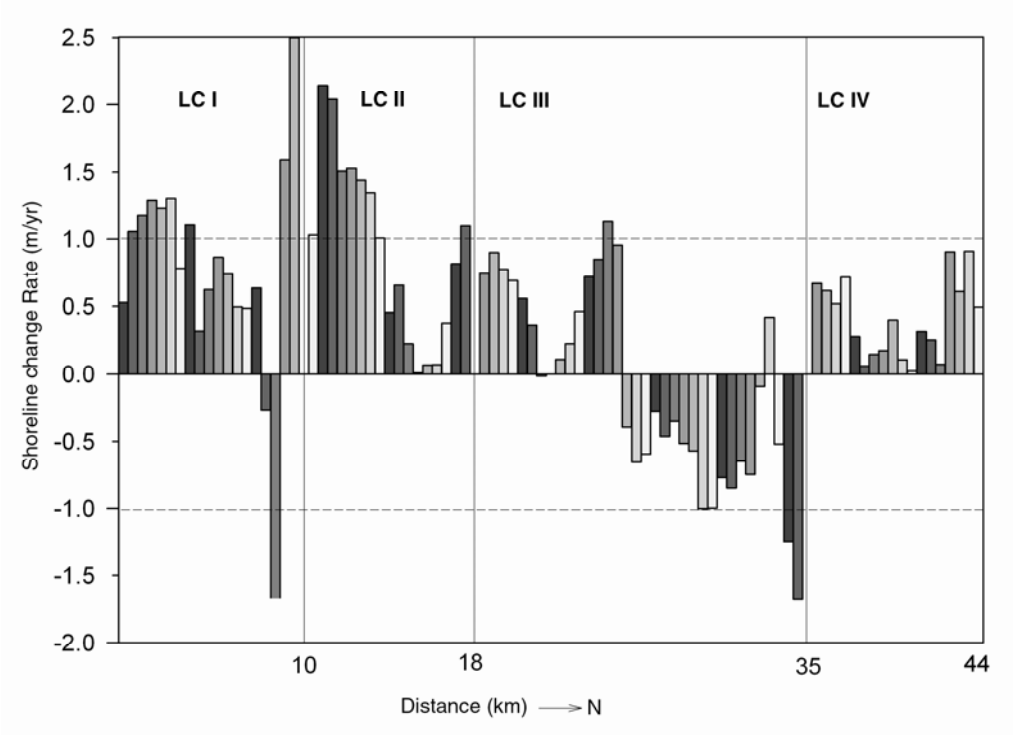

Fig. 4: Rate of change in beach width (m/yr) at each transect of all the four littoral cells. Anomalous values of accretion/erosion rates (>0.75 m/year) are associated with transects near to breakwaters, spits and inlets.

The study reveals that (i) about 57% of transects exhibit ±10 m RMSE values, indicating better agreement between the estimated and satellite-based shoreline positions, and (ii) transects closer to the cell boundaries exhibit about 50% uncertainties in

shoreline change rate estimations. Based on RMSE values, the influence of natural processes and anthropogenic factors on shoreline changes has been evaluated. The cells/transects dominated by natural processes reveal low RMSE values, whereas the cells/transects influenced by anthropogenic activities such as sand mining, construction of coastal structures, exhibit higher RMSE values. However, the variation in RMSE values is not significant if the total number of transects is considered. Erosion and accretion patterns reveal that accretion was dominant in cells LC-1 and LC-II, both accretion and erosion in cell LC-III, and maximum erosion in cell LC-IV. Further, erosion is observed in the coastal area where engineering structures such as seawalls, groynes and breakwaters are built (Fig. 4).

CHAPTER-VI: Morphology of Spits

This Chapter deals with morphological changes of seven spits in the study area. The same methods and data sets, used in Chapter-V, have been adopted in addition to statistical methods in GIS environment to quantify, and understand the changes in morphology of spits in terms of size and areal extents, dynamics and factors responsible for evolution of spits during the last 95-years. Variations and overall rate of change in length, area and coefficient of determination (R^2) of each spit are calculated separately for two periods i.e., 1910 and 1967 as base years. This attempt has been made to find out whether there is any significant change in length and area of all the seven spits that have been studied (Fig. 5).

The study reveals that majority of the spits in the study area indicate long-shore drift is a prominent cause for formation and growth of spits while river drift plays a significant role in shaping as well as growth of spits. Large variations are observed with respect to morphology and dynamics of river mouth and areal extents of all the seven spits studied. The Ullal spit shows net gain in its length and area for the entire study period, whereas, the Bengre spit reduced in its length but increased in area. Significant morphological changes are also observed in the Sasihitlu and Hejamadi Kodi spits, situated on either side of the Pavanje-Mulki river mouth. Uliyargoli-Padukere spit shows net gain of 456 m in its length but lost in area by ~0.22 M m^2 for the entire study period of 95-years. In the last 95-years, the estuarine mouth has migrated towards southeast due to erosion at the distal end of the Oddu Bengre spit and accretion at the Kodi Bengre spit.

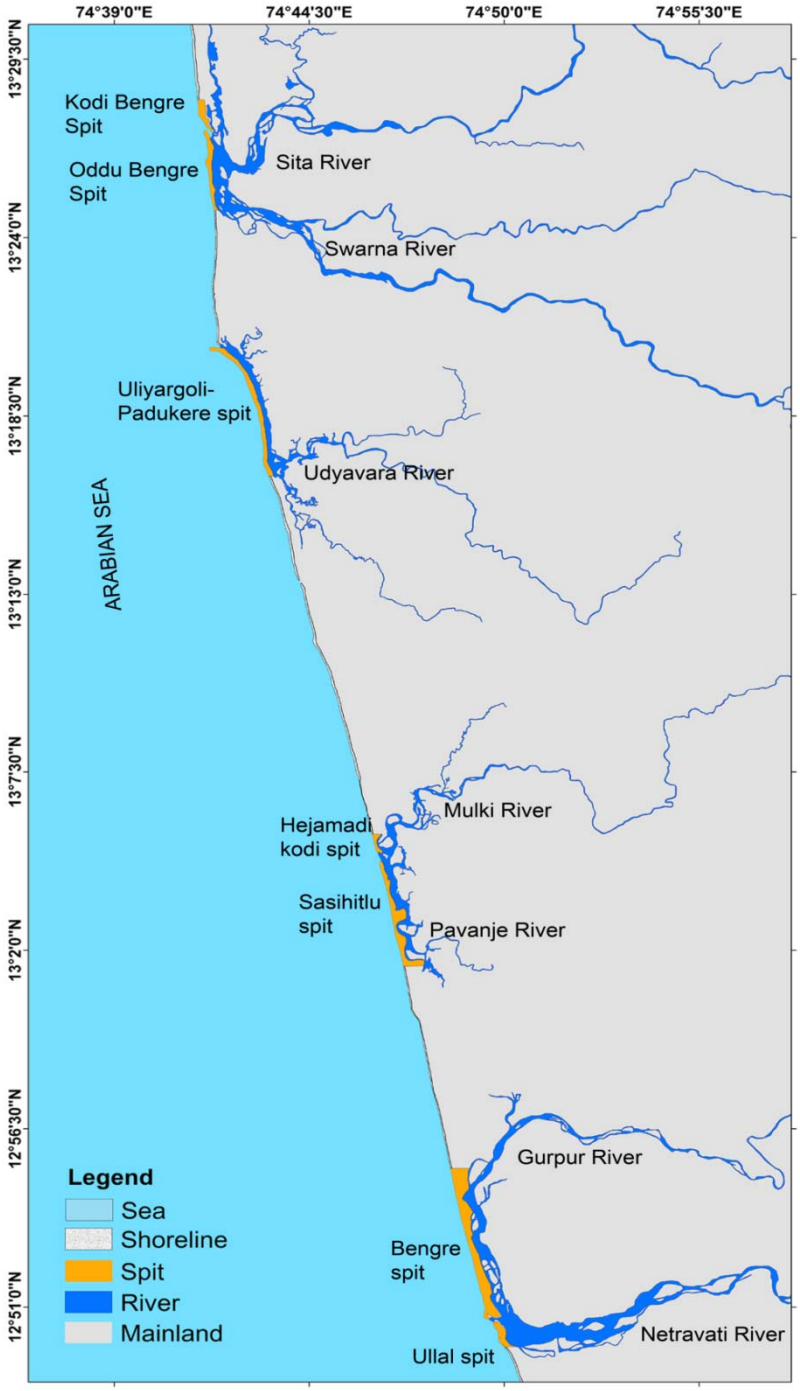

Fig. 5: Map showing the locations of various spits in the study area.

The statistical estimations of areal extents of spits reveal large variations in length and area, which can be attributed to the limited data sets available during the period from 1910-1967. However, the uncertainty in statistical estimation of spits morphology also prevailed if the coast is affected by human interventions. Hence, the present study suggests that multi-dated satellite data along with statistical techniques can be effectively used for the study of spits morphology.

CHAPTER–VII: Conclusions

In this chapter, the major conclusions drawn from the work carried out are highlighted and the scope for future work is discussed.

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